Vegetation Profile Estimates from Multialtitude, Multifrequency Radar Interferometric and Polarimetric Data

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1. INTRODUCTION

Forest vegetation profiles are key inputs to biomass determination and ecosystem modeling. With the advent of radar interferometry, microwave remote sensing is directly sensitive to the distribution of vegetation in the vertical direction [1]. Polarimetry and polarimetric interferometry further enhance vertical-profile determination [2,3]. Parameter estimation driven by simple physical models of vegetation scattering yields quantitative estimates of parameters such as vegetation height and the dimensions of vegetation layers and their relative scattering strengths. In this paper, the analysis of a JPL TOPSAR data set collected in April 1998 over Central Oregon focuses on the relative contributions of interferometric, polarimetric, and multifrequency data types to improving vegetation parameter-estimate accuracy. This data set consists of vertical-polarization interferometry at three radar altitudes, 8 km, 4 km, and 2 km at C-band (5-cm wavelength) and L-band (25 cm), and full polarimetry at C-, L-, and P- (80 cm) bands. After a brief description of the data set, a description of the simple physical model used to estimate vegetation profile parameters is followed by a description of the data set and the results.

2. THE MULTIBASELINE, MULTIFREQUENCY INTERFEROMETRIC AND POLARIMETRIC DATA

The Jet Propulsion Laboratory's AIRSAR system acquired interferometric TOPSAR data [4] at three different altitudes, 8 km, 4 km, and 2 km over Central Oregon in the Metolius River Basin in April 1998. Because interferometric sensitivity is proportional to the baseline divided by the altitude [1], flying multiple altitudes is equivalent to acquiring multiple baselines. At each altitude, single-transmit and pingpong mode produced two baselines. The physical baseline is 2.45 m at C-band, and that is effectively doubled with pingpong mode. A redundancy was built into the acquisition strategy, because, for example 8 km pingpong interferometric data should be equivalent to 4 km single-transmit mode. Many systematic effects have been diagnosed using this redundancy. L-band interferometric data at a 2.00-m physical baseline were simultaneously acquired. Four race tracks were flown, three for interferometry, and one for C- and L-band zero-baseline polarimetry. The polarimetric interferometric data acquired in 1999 suffered from very poor signal-to-noise and must be reacquired in the future. Field measurements of tree height, height-to-base-of-crown, crown dimensions, leaf area index and density, and topography were made at each of 20 1-hectare stands. Profiling results will be compared to these field measurements.

3. SIMPLE PHYSICAL MODELS OF VEGETATION SCATTERING

Simple models of the radar observations as a function of vegetation characteristics have the extreme advantage that they can be specified with a small number of parameters. Since the radar observation set is frequently of the order of ≈ 10 observations per resolution cell, more complex models are inadequately determined by most remote sensing data types. The value of a simple model must be determined by the integrity of the parameter estimates when compared to field measurements. If disagreement between parameter estimates and field-measurement forest characteristics is too large, increased model complexity must be explored.

In this analysis, the forest vegetated land surface is taken to be a randomly oriented vegetation volume over a ground surface [2]. For the C-band data, the ground surface is taken to be slightly-rough, inducing a direct ground return only, and for the L-band data, the surface is taken to be fairly smooth, inducing only a specular, ground-volume return. The vegetation volume is allowed to have a scatterer-number density dependence on altitude, and estimating this dependence is the aim of this report. Field measurements suggest that Gaussian, or multiple Gaussian density profiles are a better description of the forest vegetation than slab models. From references [1] and [2], at C-band, the interferometric cross correlation of signals and end 1 and end 2 of the baseline, and the polarimetric horizontal to vertical power ratio $HHHH/VVVV$ can be expressed in terms of vegetation parameters as follows:

$$\begin{pmatrix} \text{Int Amp}_{8\ km} \\ \text{Int Phase}_{8\ km} \\ \text{Int Amp}_{8\ km\ ping} \\ \text{Int Phase}_{8\ km\ ping} \\ \text{Int Amp}_{4\ km} \\ \text{Int Amp}_{4\ km\ ping} \\ \text{Int Amp}_{2\ km} \\ \text{Int Amp}_{2\ km\ ping} \\ \text{Pol HHHH/VVVV} \end{pmatrix} = \mathbf{M} \begin{pmatrix} \text{Veg Height} \\ \text{Peak Extinction} \\ \text{Density Center} \\ \text{Density std} \\ \text{Ground/vol} \\ \text{Gnd diel.} \\ \text{Topography} \end{pmatrix} \quad (1)$$

where "Int Amp" means interferometric amplitude, and the last entry in the observations on the left is the polarimetric horizontal to vertical power ratio. The reason for choosing only this polarimetric quantity in the absence of polarimetric interferometry is detailed in [2]. The physical model $\mathbf{M}$ relating the observations on the left of (1) to the parameters on the right relies on randomly oriented volumes over slightly-rough ground surfaces, and is also described in [4]. The extinction coefficient $\sigma_x(z)$ is modeled with the parameters above as a Gaussian as a function of altitude z:

$$\sigma_x(z) = \text{Peak Extinction} \times \exp\left[\frac{(z - \text{Density Center})^2}{2(\text{Density std})^2}\right] \quad (2)$$

The L-band interferometric amplitudes and phases at 4- and 2-km altitudes and the polarimetry can be added to the parameter estimation scenario in (2). With nine additional L-band observations, two new parameters will have to be added, "Peak Extinction" and "Ground/vol" parameters for L-band. Assuming that all C-band phases will also be used, the following parameter estimation scenario will then be tried, with subscripts denoting the band:

$$\begin{pmatrix} \text{Int Amp}_{8\ km_C} \\ \text{Int Phase}_{8\ km_C} \\ \text{Int Amp}_{8\ km\ ping_C} \\ \text{Int Phase}_{8\ km\ ping_C} \\ \cdot \\ \cdot \\ \cdot \\ \text{Int Amp}_{4\ km_L} \\ \text{Int Phase}_{4\ km_L} \\ \text{Int Amp}_{4\ km\ ping_L} \\ \text{Int Phase}_{4\ km\ ping_L} \\ \text{Int Amp}_{2\ km_L} \\ \text{Int Phase}_{2\ km_L} \\ \text{Int Amp}_{2\ km\ ping_L} \\ \text{Int Phase}_{2\ km\ ping_L} \\ \text{Pol HHHH/VVVV}_L \end{pmatrix} = \mathbf{M} \begin{pmatrix} \text{Veg Height} \\ \text{Peak Extinction}_C \\ \text{Density Center} \\ \text{Density std} \\ \text{Ground/vol}_C \\ \text{Gnd diel.} \\ \text{Topography} \\ \text{Peak Extinction}_L \\ \text{Ground/vol}_L \end{pmatrix} \quad (3)$$

For this first attempt at estimating Gaussian profile parameters, the only interferometric phases used were Int Phase$_{8\ km_C}$ and Int Amp$_{8\ km\ ping_C}$. All other phases were downweighted and essentially ignored in the parameter estimation because there appears to be systematic shifts between phases at different altitudes and frequencies. The only current candidate explanation for these shifts is that each case was processed with different reference parameters. This will be corrected and the full observation vector will be used in the future. The parameters estimated are as shown in (1) and (3).

4. RESULTS

Figure 1 shows three Gaussian profiles of scatterer number density for three forest stands, calculated from the first, third, and fourth parameters above. The profiles are relative in that the peak density for each stand is set to 1.0. Stand 1 is a mixed-height stand of Ponderosa Pine, with

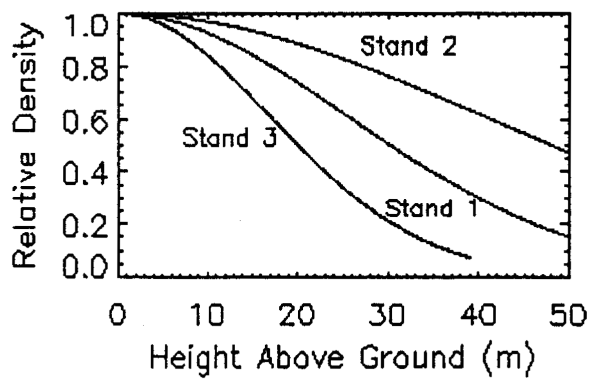

Figure 1: Relative Gaussian density profiles of three forest stands in Central Oregon from multi-altitude AIRSAR interferometry + polarimetry.

most trees about 12 m and a smaller number about 40 m. Stand 2 is old growth, of more uniform density and height 40 m. Stand 3 is a young, dense stand about 15 m tall.

The profiles of Figure 1 exhibit qualitative agreement with field measurements, but show errors as well. For example, the estimated profile for stand 2 is broader than that for either stand 1 or stand 3, which is correct, but the estimated stand 3 profile, which has no tall component, should be substantially narrower than stand 1, which does. All three stands' densities extend beyond the actual maximum tree height. These errors could be indications of instrumental calibration errors and/or modeling errors. Part of the error in the parameters generating Figure 1 could be due simply to the exclusion of the lower-altitude and L-band phases. Once those measurements are included, parameter performance should improve. Also, the slightly-rough-surface approximation, that surface roughness is less than a C-band 5.6-cm wavelength, may not be appropriate for this terrain. Fully polarimetric interferometry would obviate the need for this assumption [2].

Figure 2 shows the field-measured leaf-area-density along with the profile of stand 1, both arbitrarily normalized. The C+L-band estimated profile is shown along with the C-band results of Figure 1. There is qualitative agreement with the field measurements, and adding L-band data is consistent with the C-band-only solution, but does not improve the agreement with field measurements much. L-band's failure to add much to this analysis is due in part to the small physical baseline of 2 m, and the addition of L-band at larger baselines, perhaps from repeat-pass data, should improve the parameter performance. Polarimetric interferometry should also help to more accurately characterize the ground return, which was substantial for these stands. In future analyses, AVIRIS-determined leaf-area-indices will normalize the profiles [5] in Figure 2. Again, the agreement is reasonable, given that this is the first attempt to recover vegetation profiles from this type of data. Some of the discrepancy between the radar estimates and field measurements in Figure 2 is due to parameter estimate error, and some is due to systematic instrumental and modeling error. A full accounting of parameter estimate errors and the covariance between parameters will clarify how to improve Figure 2 with these and future data.

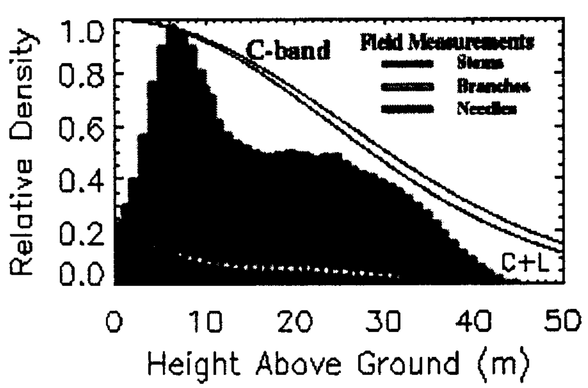

Figure 2: C- and L-band relative Gaussian density profiles of Stand 1 from radar and field-measured leaf area density.

5. SUMMARY

Remote sensing of vegetation structure is an important component of biomass measurement and ecosystem modeling. A set of parameters describing Gaussian vegetation profiles were estimated from multialtitude AIRSAR interferometry, which is equivalent to multibaseline interferometry, plus zero-baseline polarimetry. While there is reasonable agreement between profiles estimated from radar and those measured in the field, both instrumental and modeling enhancements should improve this first attempt at the quantitative estimation of profile parameters from interferometry and polarimetry.

6. ACKNOWLEDGMENT

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7. REFERENCES

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